Investigation of Chaotic Instability in Brake Squeal

Paul A. Meehan *

* *The University of Queensland, Brisbane, Australia*

Abstract. The occurrence of chaotic motion in a vehicle instability phenomenon known as brake squeal is investigated. Brake squeal is a high-pitched noise that occurs sometimes when a vehicle is braked using disk brakes. The equations of motion for the two dominant coupled modes of the brake system reduce to two autonomous coupled nonlinear second order systems. The mode coupling instability via friction causes limit cycle behaviour via a Hopf bifurcation. This limit cycle is shown to break up into chaotic motion characterised by a phase space with funnel-like structure and an approximate one-dimensional attractor, similar to that found in a forced dry friction oscillator. Conditions under which chaotic instability occurs are identified and discussed. The results provide insight into the occurrence and avoidance of very loud squeal not characterized by a pure tone.

Introduction

Brake squeal is a high-pitched tonal noise that occurs during braking of a vehicle using disk brakes. It has been shown to occur due to a friction induced instability of at least one brake system mode of vibration that grows to a nonlinear limit cycle. For the automotive and railway industries, this causes excessive noise and vibration resulting in excessive customer complaints and warranty costs [1]. There have been several mechanisms of brake squeal investigated, as reviewed in [4], including; falling friction with increasing sliding speed, sprag-slip [5] and modal coupling. A comprehensive review of research into chaotic motion in brake squeal and other friction coupled systems is provided in [1]. Feeny and Moon [2] identified chaos in a harmonically forced spring mass system with dry friction both experimentally and numerically using different friction laws and found chaotic attractors with a funnel-like structure. The transition from a limit cycle to an unstable torus attractor was also identified in [1]. More recently, Lin et al [3] identified and controlled brake disk squeal at lower damping using state feedback control and Meehan et al [6] identified chaotic motion in railway wheel squeal both numerically and analytically. In this paper we extend the numerical and analytical modelling of railway wheel squeal to the occurrence of chaotic instability in fundamental and realistic models of brake squeal to provide more insight into its occurrence and avoidance.

Results and discussion

A reduced brake squeal model is modified and developed, that includes the dominant brake mode coupled dynamics and a nonlinear friction model proposed and tested by [2]. The analytical methods for determining the local instability occurrence and limit cycle amplitude of squeal oscillation under bilinear creep approximation are then described. The full nonlinear time domain model consisting of to two autonomous coupled nonlinear second order systems, is numerically solved using the fourth and fifth order Runge–Kutta routine as part of DYNAMICS, written by Nusse and Yorke or the Radua method in MathCad 15.0 at a sampling rate of at least 50 times the squeal natural frequency. The nonlinear phenomena was investigated using the time history, phase space and bifurcation diagrams of Poincaré maps and Lyapunov Exponents. An example phase space under chaotic instability is shown in *Figure. 1*.

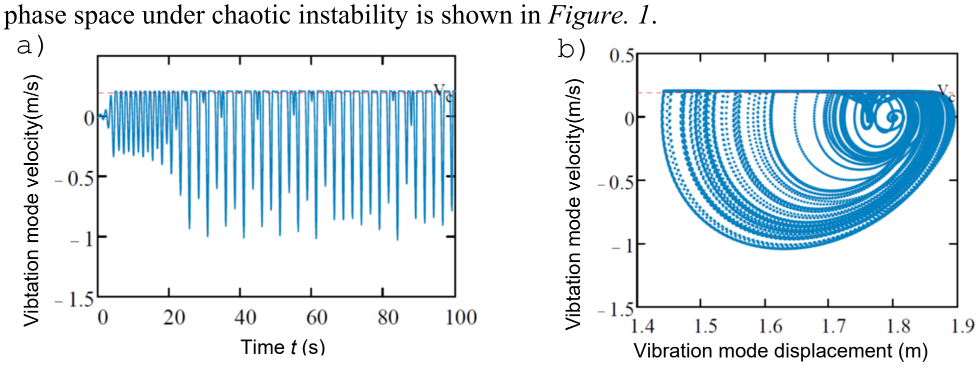

Figure. 1 ***a) Simulated time history and b) phase space of brake squeal vibration growth (-)under mode coupling, θ=21.1°***

The conditions under which chaotic instability under mode coupling are investigated and identified in both a fundamental and real brake system model to provide insight into the occurrence and avoidance of very loud brake squeal not characterized by a pure tone.

References

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